

The influence of the Level of Detail (LOD) and the surrounding materials reflectance on the assessment of the photovoltaic potential in urban environments

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Abstract

In order to assess the photovoltaic potential of a building in an urban environment, the creation of a 3D model is necessary. However, there are many different levels of detail (LOD) to model a building. In this report, we compared the three main LODs according to the *CityGML* (1) and evaluated the relative error of solar irradiation between them through four case studies in the city of Neuchâtel (Switzerland). Furthermore, we determined if the impact of an exact modelling of surrounding materials properties has an influence on the studied buildings irradiation. The three LOD models are designed with the software *Rhinoceros*, using the Digital Surface Model (DSM), the Digital Terrain Model (DTM) and on a basis of a visual survey through *Google StreetView*. Through *DIVA-for-Rhino*, we assigned materials to our model and run the simulation of solar radiation using a Daysim simulation engine. The results highlighted the overestimation of the PV potential for buildings using LOD1 and LOD2 models considering LOD3 as the ground truth. Using the found relative errors, this method could assess the PV potential at the urban scale more precisely without needing a complex model.

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Introduction

Resources of fossil energy are decreasing and have become scarce, thereby the demand of a bigger part of renewable energy requires a special regard. The development of solar decentralized energy systems is one of the possible solutions to face this problem. Researches about PV cells which are more efficient with lower irradiation values can promote the use of Building-Integrated photovoltaics (BIPV) implementing panels on the facades or in the glazing.

Research context

In an urban environment, the assessment of the solar potential is unavoidable to determine the electricity the system can generate with photovoltaic (PV) panels. To assess the PV potential in this environment, creating a 3D model is necessary. The city OGC standard CityGML (1) defines 5 principal levels of details (LOD) as shown in Figure 1:

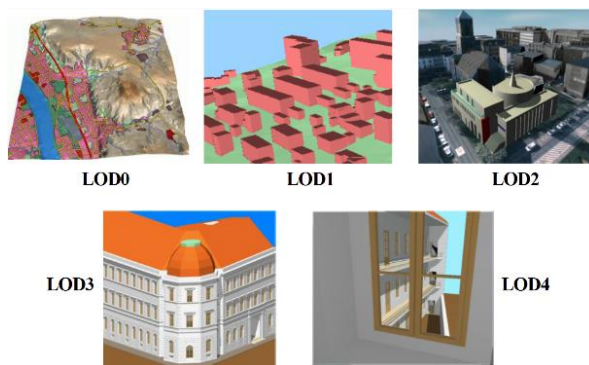


Figure 1 the five levels of detail (LOD) defined by CityGML (1)

The LOD0 is the coarsest level of detail, it can be built with a simple aerial image or a topographic map. Buildings are represented as polygons of roof. In LOD1, the buildings are defined as blocks, prismatic with flat roofs. The middle class of accuracy is the LOD2, different types of roofs and multiple surfaces for the façades are defined. With a database of Digital Surface Model (DSM) and Digital Terrain Model (DTM) or LiDAR-based 3D models ((4) Jakubiec & Reinhart, 2013), LOD1 and LOD2

models can be automatically built. However, this automation can generate some inaccuracies that need manual work to be corrected.

The LOD3 is the highest class of accuracy for the building outside surfaces, this is a detailed architectural model for wall and roof structures including doors, windows, balconies, chimneys, overhangs and dormers. The advantage of this level of detail is that it is the most detailed model regarding the building-integrated photovoltaics. This is because all obstructions are modelled, thus the available place for PV panels is realistic. Therefore, to evaluate a building PV potential, the consideration of LOD3 as the ideal modelling and representative of the reality is done. The drawback of this level of detail is the time to create the model. Indeed, parts of the building as the facades, cannot be automatically built, that implies more complicated methods to create it and thus, more time.

The LOD1, 2 and 3 with intermediate spaces, are commonly used in practice to study external impacts as building shadows for example ((3) Biljecki; Ledoux Hugo & Stoter, 2016). The LOD4 adds to the LOD3 the interiors structures as rooms, stairs, interiors doors... This is not useful in our context. This paper presents a comparison of solar irradiation between the three levels of detail LOD1, 2 and 3.

Objectives

The first aim of this project is to evaluate the relative error of PV potential between the different levels of detail regarding the LOD3 as the ground truth. Secondly and part of a subproject, we determined if the impact of an exact modelling of surrounding materials proprieties has an influence on the studied building irradiation. As ultimate goal, we expect the results to provide guidance on which workflow afford the best trade-off in terms of accuracy of the results and time necessary to produce them.

Methodology

Case studies choices

The purpose of the project is to compare buildings from different type, we chose therefore four different districts in the city of Neuchâtel and select four representative buildings as shown in Figure 2:

- 1st building: This five-story building is typical of old town, there are narrow spaces between it and the surrounding ones. It is a hip roof with two dormers, some chimneys and windows. The façades have got four stages.
- 2nd building: This gable roof villa/ twin house is in a suburban area, the closer surrounding building is at approximately 20m. There is vegetation around it.
- 3rd building¹: Office flat roof building.
- 4th building: Six stages apartment building, well exposed to the sun with big balcony facades.

Firstly, the assessment of the relative error of PV potential between the different levels of detail is calculated for the four buildings. Secondly, in the theme of a sub-project, the assessment of building's irradiation with an exact modelling of surrounding materials proprieties is evaluated for the 1st and 2nd building.

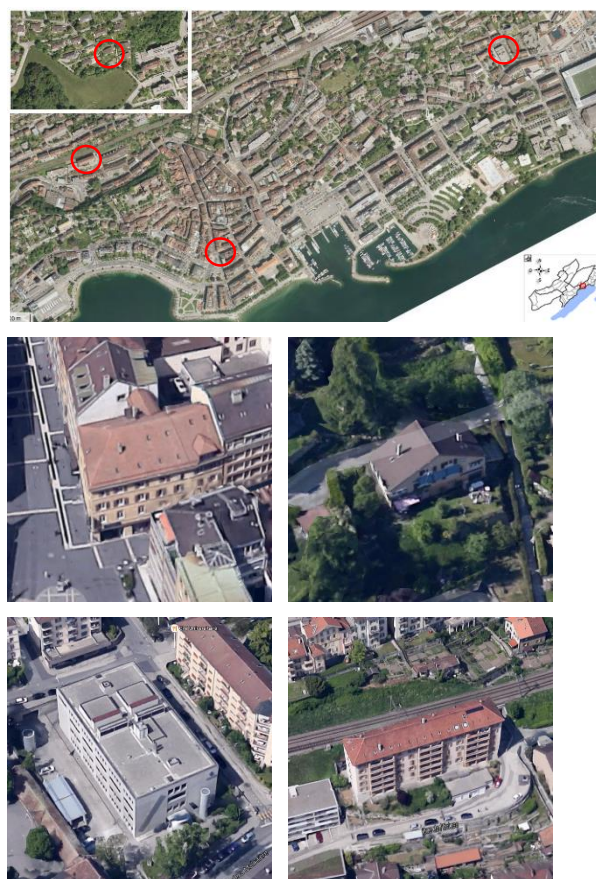


Figure 2 Building 1 to 4: Four case studies in the city of Neuchâtel

Modelling

The first step of this experiment is to model the three levels of detail (LOD1, 2, 3). LOD1 and LOD2 models are automatically reconstructed from the Digital Surface Model (DSM) and Digital Terrain Model (DTM) of the city of Neuchâtel. These coordinates were provided for this project ((2) Peronato, Rey & Andersen, 2015). The DTM point's coordinates are used to create the ground surface. Some errors due to the automated reconstruction, as the shape of the surrounding buildings' roof, were corrected with the DSM.

Starting from LOD2, the creation of LOD3 is constructed adding details such as, for the façade, windows, doors and balconies and for the roof, chimneys, windows, dormers... The

¹ Buildings 3 and 4 are studied by my colleague Jérémie Stoeckli

LOD3 is modelled with a minimum precision of 0.5m according to the CityGML (1) estimated by visual assessment with tools like *Google map*, *Google StreetView* and *geoplanet Neuchâtel* (5). The details structures on the roof as the chimneys and dormers can be drawn with the DSM points. The model was designed with the software *Rhinoceros*.

Figure 3 shows the three levels of detail for the first and second building. As explained, LOD1 represent the building as a block with flat roof and low accuracy level. LOD2 represent the building with its real footprint and the sloping roof corresponding to the DSM points. The overhangs are not done in this middle class of accuracy. In LOD3, the external details as the windows, chimneys and dormers are represented and the overhangs are modelled.

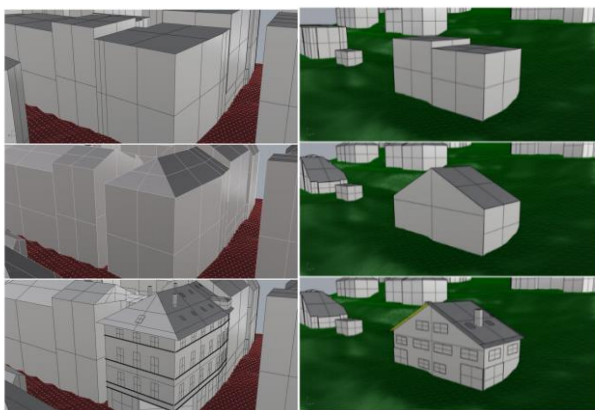


Figure 3 Rhinoceros pictures - Example of the three LOD models for the first two buildings

Materials assignment and solar radiation simulation

Through *DIVA-for-Rhino*, we assign materials to our model and run the simulation of solar radiation from a weather file for the city of Neuchâtel using the Daysim simulation engine. The distance between the calculation nodes is chosen as one meter to avoid too long simulation. For the irradiation on a node, one reflection on others materials is chosen in addition to the direct sun rays and the sky luminosity.

The different materials are assigned to evaluate the influence of reflectance of

surrounding objects. The distinction of two types of reflectance values is made: one texture for the ground and one for all buildings.

To analyse the results, the building's irradiation is calculated for a minimum solar irradiation threshold, which consider only the model's nodes with a higher irradiation value. This consideration of thresholds is necessary to assess the possibility of implementing PV panels. A nodes with a lower irradiation than this value is considered unusable for PV panels.

1st building

The first part of the project is to assess the difference of PV potential regarding the level of detail of the model. For this part, we assign default materials proprieties for the ground and for the surrounding building (10% reflectivity for the ground and 30% reflectivity for the surrounding buildings (*DIVA* database)).

For the rest of the calculations, the reflectivity of the ground is considered 10%. According to ((7) *Lighting Materials for Simulation, 2015*), the asphalt has a reflectivity between 8% (new asphalt) and 12% (old asphalt). Thus, a reflectivity of 10% is representative of the ground in front of the building.

For the analysed buildings, a reflectivity of 30% (*DIVA* database) is taken. It is a global average for different types of buildings. E.g. reflectivity of some materials according to (7): Concrete wall (24%); bright exterior wall (42%); green aluminium overhang (30%), an old white street paint (42%).

To assess the impact of materials on the building's irradiation, the choice to vary reflectivity of surrounding and case study buildings is done. For the simulation of each level of detail, we determine three possible reflectivity, 10, 30 and 70%. Table 1 summarizes the material characteristics for each simulation.

Model	Ground	Buildings
LOD1	10 %	10 %
	10 %	30 %
	10 %	70 %
LOD2	10 %	10 %
	10 %	30 %
	10 %	70 %
LOD3	10 %	10 %
	10 %	30 %
	10 %	70 %

Table 1 Materials reflectivity for the simulations

2nd building

As this building is in a suburban environment, there is more interspace between houses. The shadings and reflectivity of surrounding buildings cannot influence the irradiation on our case study. The reflectivity of buildings is set to 30%. DTM coordinates is used to model the terrain, therefore we supposed that there is not any vegetation around houses.

In this system, the ground has more repercussion than the others buildings. First of all, as a basis materials, the ground is 20% of reflectivity, which corresponds to a grass of medium size ((6) BEMBook, Ground Reflectance, 2012). For the second part of the project, to assess the influence of the ground, we compared a summer ground and a winter ground. To model the snow, according to ((6) BEMBook, Ground Reflectance, 2012), a reflectivity of 50% is chosen, which corresponds to a snow typically from rural site. It will be compare to a snow reflectivity of 75% (fresh snow).

To assess the impact of snow, we compared two simulations regarding weather data: one with all the year a grassy ground and the other one with snow the days there is snow on the ground. According to a 2005 weather file, this corresponds to 40 days a year. Afterward, the PV potential gain modelling the snow is calculated for the interesting surfaces of the building.

Results

Relative error due to the LOD – 1st building case

Figure 4 shows the irradiation of the building surfaces for different irradiation thresholds and the three levels of detail. For the 400 kWh/m² threshold, the façade has about the same irradiation between the three LODs, except for the LOD3 as it loses irradiated surface due to the windows and the overhangs. We perceive that the façades cannot reach the 800 kWh/m² threshold. Moreover, at this same threshold, for the LOD2 and LOD3 the part of the roof exposed to the North is lost. At the last threshold, only the well exposed and sloping surfaces receive irradiation.

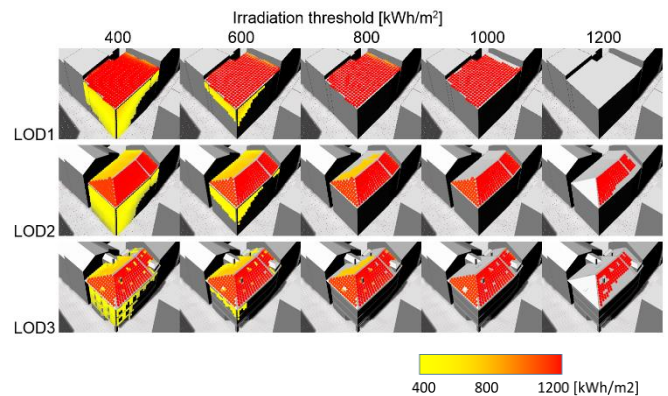
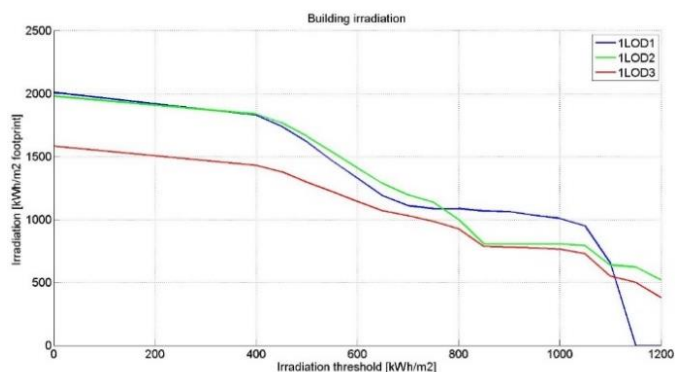


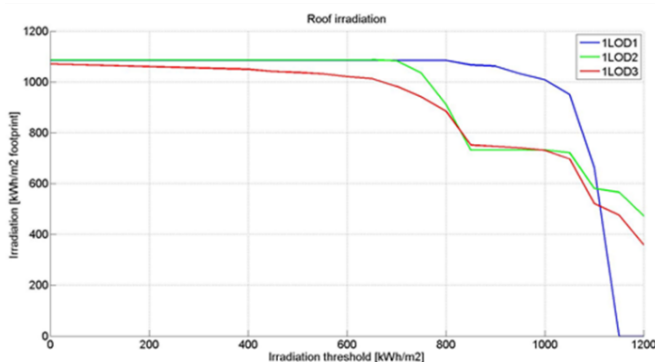
Figure 4 Surfaces irradiation of the building for different irradiation thresholds and the three Level of Detail (LOD)

The Graph 1 indicates the annual irradiation for the entire building [kWh/m²_{footprint}] in function of the thresholds [kWh/m²] for the three levels of detail. The irradiation is normalized to the building footprint in order to compare buildings of different geometry.



Graph 1 Building irradiation in function of the irradiation thresholds

This graph shows a linear decrease of the irradiation for the three LODs between the 400 and 750 kWh/m² thresholds. This is due to the regular irradiation losses on the façades. In this interval, the curves LOD1 and LOD2 are approximatively at the same level because in the model, the façade details are the same and nothing hides them. However, the LOD3 curve is lower because of the surface losses due to the windows and the overhangs. After the 800 kWh/m² threshold, no more façade are exposed, so it is interesting to focus on the roof. The same type of graph as Graph 1 is built (Graph 2) considering only the surfaces of the roof.



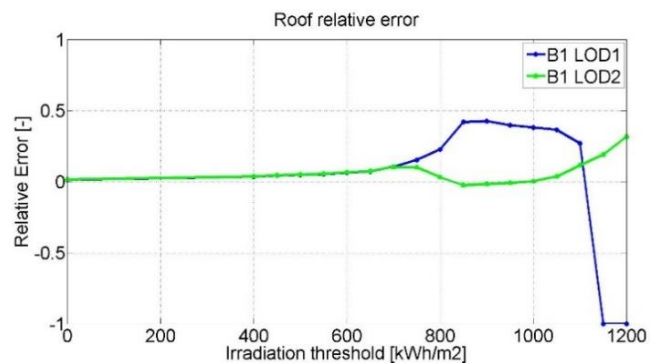
Graph 2 Irradiation of the roof surfaces [kWh/m² footprint] in function of the thresholds [kWh/m²]

For the LOD1, we observe that the roof is irradiate constantly until 800 kWh/m² threshold, then it losses some little irradiation due to the highest neighbour's building. All the points on the horizontal roof are irradiate at the same level of 1100 kWh/m². So for a highest irradiation threshold, no more point is irradiate. For the LOD2 and LOD3 curves, we perceive two sharp decreases: The first one at the 800 kWh/m² threshold due to the loss of the north surface. The second one about the 1100 kWh/m² threshold due to the loss of the west surface of the roof.

In general, the LOD3 curve is lower than the LOD2 one due to the chimneys, windows and the dormers. However, at the 900 kWh/m² threshold the irradiation is bigger for the LOD3. It can be hypothesized that, for the 900 kWh/m² threshold, the residual surfaces are the south and west one. On them, there are chimneys

and windows but in the LOD3 model, there are the overhangs. The area gained for the overhangs (45 m²) is bigger than the lost one of the chimneys, windows and dormer (20 m²) at the same irradiation threshold. For these two models, the highest irradiation threshold is about 1250 kWh/m² on the top of the south surface of the roof.

As said before, if we take the LOD3 as the "perfect" modelling the reality, we can check the relative error for LOD1 and LOD2. The relative error of the roof is expressed in Graph 3.



Graph 3 Relative error of LOD1 and LOD2 in function on the irradiation threshold

For a smaller threshold than 700 kWh/m², the relative error is the same for the LOD1 and LOD2 and is smaller than 10%. After that, there is a big difference between LOD 1 and 2: The error of LOD1 increases until 40%. It is because the LOD1 does not take in account the north surface of the roof so at 900 kWh/m² there is more irradiation on the LOD1 model than on the LOD3. The LOD2 relative error decreases to 5% for the surfaces well exposed. As said, the LOD2 curves is negative because there is more irradiation on the LOD3 model due to the increasing area. Then the error increases until 30% at 1200 kWh/m² irradiation threshold. The irradiation on the LOD1 model ends at 1100 kWh/m² threshold, above this value, the relative error is -1 because there is no more irradiation.

The relative error of the facades and the roofs is made for each building and will be analyse below. From these correction factors, this is possible to produce accuracy results of the

solar irradiation from a LOD1 or a LOD2 model, it means a gain of cost without doing a LOD3 model.

Relative error comparison for the four buildings²

The graphs obtained by plotting the curves described in the section above, as well as a mean relative error, are presented in the Figure 5 (LOD1) and Figure 6 (LOD2).

In the figure for the roof in LOD1 (Figure 5 (2)), we can see that the error committed on the roof can be highly positive (building 3), almost zero (buildings 1 and 2) or even negative (building 4) for thresholds under 700 [kWh/m²]. Those differences are mainly due to the overhangs, absent in the building 3 (flat roof) in contrary to the three others, with a bigger one for the building 4 than for the first and second one.

On the façades (Figure 5 (3)), this error is almost always positive, due to all the area losses caused by addition of balconies and windows, which represent a big proportion of this surfaces. And in contrary to the roof with the overhangs, there are no added surfaces to compensate those losses.

Looking at the building results in LOD1, we can see that the PV potential of a building is almost always overestimated for all different kinds of building. In this representative sample, only one building has negative relative errors for thresholds under 1150 [kWh/m²], and only for thresholds between 900 and 950 [kWh/m²]. This means that the probability to underestimate the PV potential of a building is really low.

In LOD2 (Figure 6), almost the same phenomenon can be observed. The errors done are a little bit lower, especially for the roof thanks to the similar shape of the roof between LOD2 and LOD3.

Even though, all those curves show that the error done by using LOD1 or LOD2 models

can't just be neglected, because the order of magnitude of the main error is a hundred percent for the façades and a little bit lower for the roof and the whole building, but still significant. It is also impossible to tell that the error done is the same for all the buildings, because the difference between the building with the biggest error and the one with the smallest is huge (some hundreds of percent in the worst case).

But something that could be taken out of those results is the main error done by using LOD1 or LOD2 models. Indeed, it would be useful to assess the PV potential of an urban area. Using one of those models, a lot easier to do than an LOD3 one, the results obtained by multiplying by a correction factor corresponding to this main error would be much more precise without a lot of efforts.

The errors done with LOD1 and LOD2 models are of the same order of magnitude (Figure 7). Depending on the difference of difficulty to model in LOD1 or in LOD2, it could be good enough to use an LOD1 model only.

With this method, meaning modelling in LOD1 or LOD2 and multiplying by a correction factor depending on the threshold, the error done by assessing the PV potential can be drastically reduced.

² This section has been written in collaboration with Jérémie Stoeckli

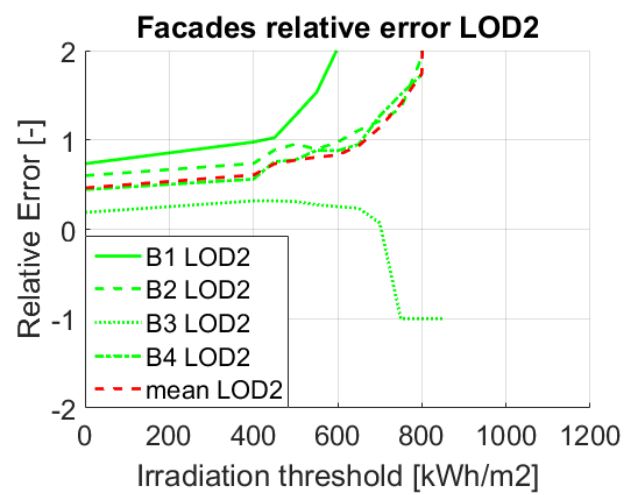
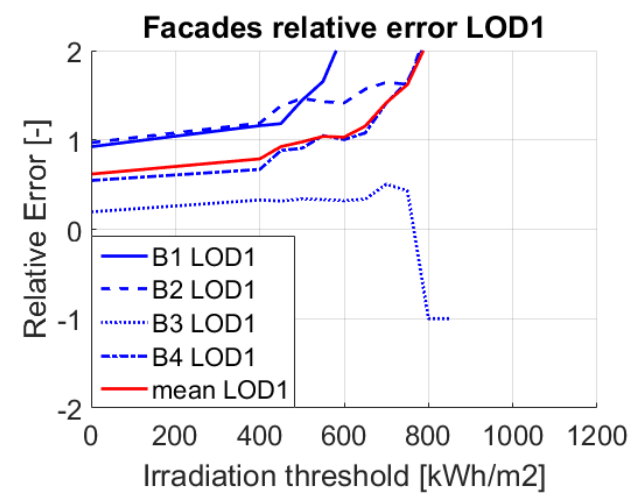
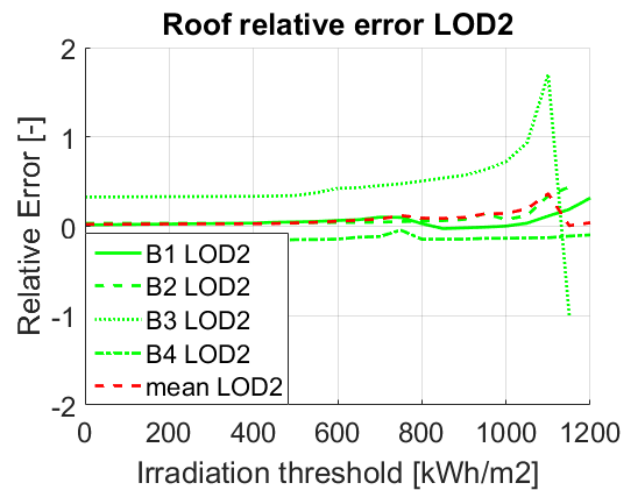
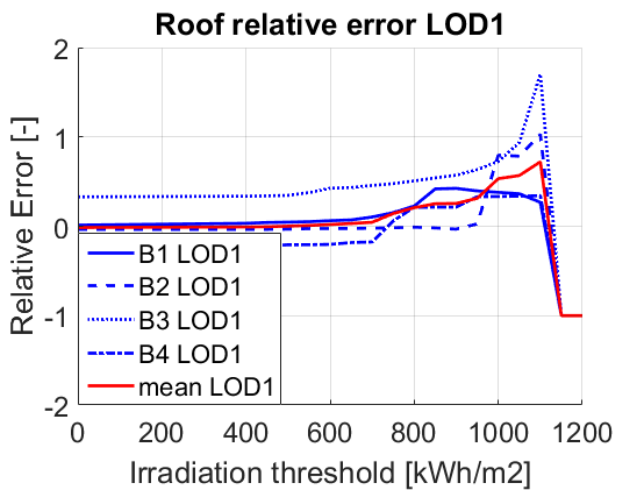
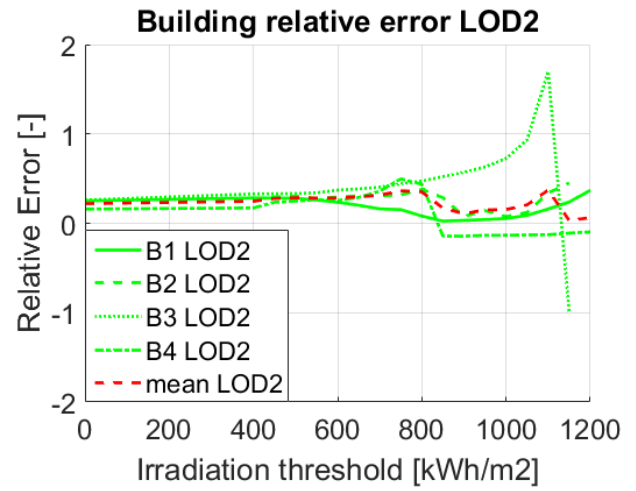
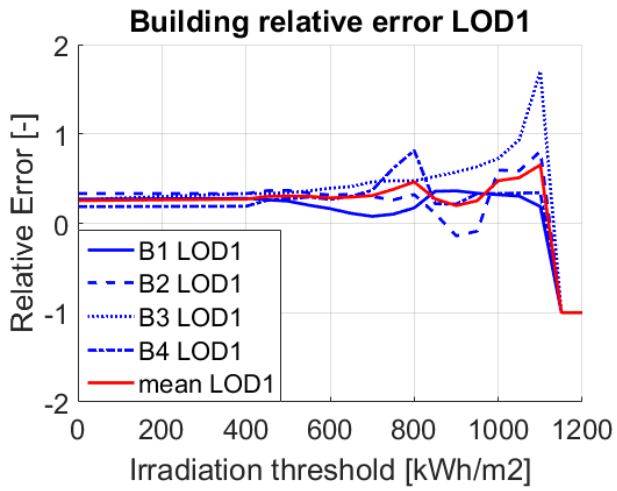


Figure 5 LOD1 relative errors of the four buildings and the mean relative error

Figure 6 LOD2 relative errors for the four buildings and the mean relative error

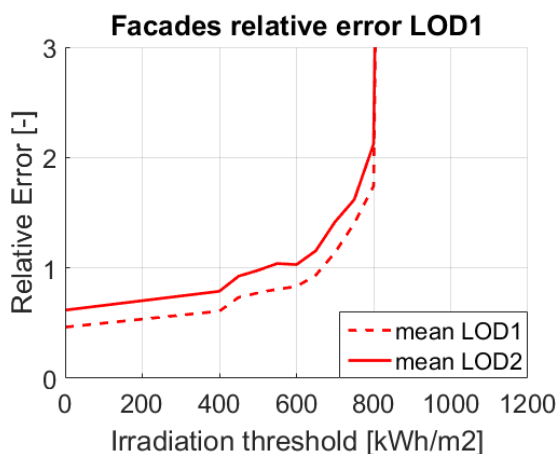
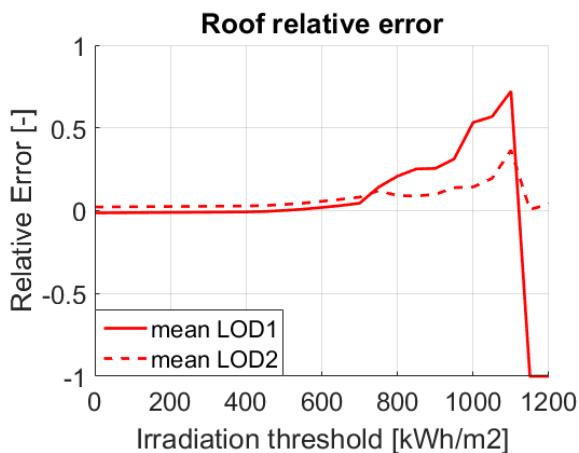
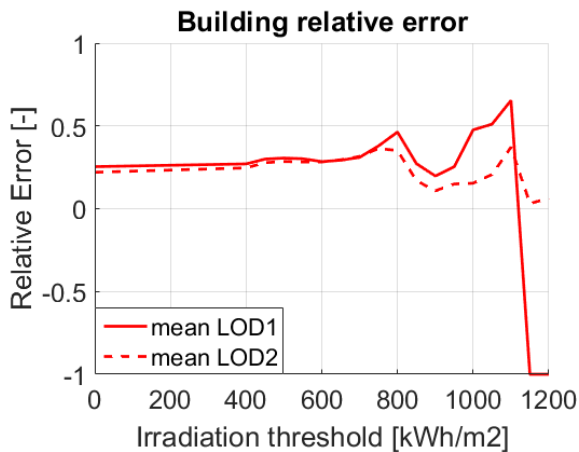


Figure 7 Comparison between LOD1 and LOD2 mean relative errors

Influence of materials reflectance

1st building

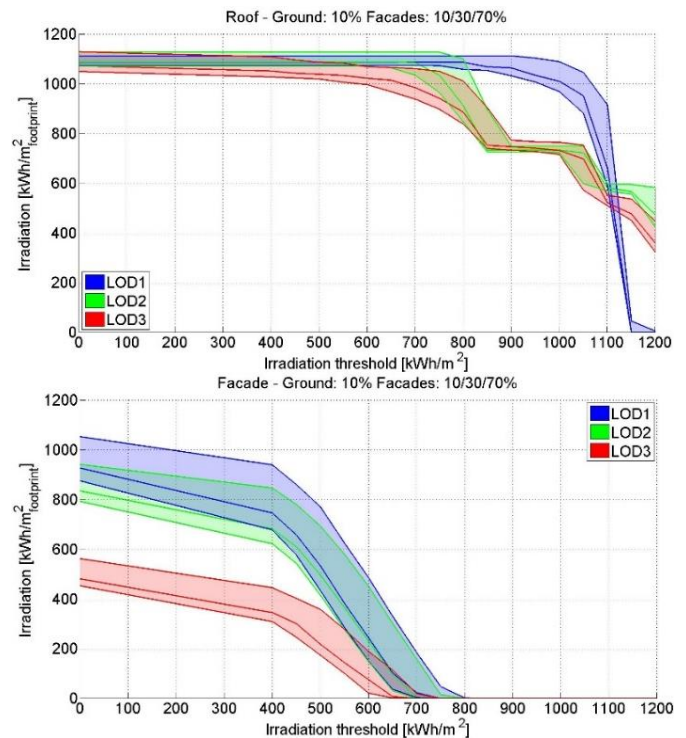


Figure 8 Roof and facades irradiation in function of the Levels of Detail and the different surrounding materials reflectivity

Figure 8 shows the irradiation on the roof and on the facades for the three levels of detail and the different reflectivity of surrounding materials (10, 30 and 70%). Overall, the difference of irradiation on the roof is smaller than on the facades regarding the different reflectivity. It should be noted that it is when there is a sharp decrease that the difference of materials reflectivity plays a bigger role. This is when a façade is losing the irradiation that a lighter/darker surrounding surface could influence the result.

For the roof and for all thresholds, the irradiation is approximatively the same for LOD2 and LOD3. In this case, assigning exact materials properties is not an advantage due to the loss of time. The results would be precise enough creating a LOD2 model with default materials without the need for a LOD3 with detailed material proprieties. This is because the surrounding building does not much affect this roof. However, the results might be different in a case study where the surrounding

building are much higher or in a terrain with steep slope.

For the façades, the irradiation can change more than 20%. As seen before, at 800 [kWh/m²], no more façades are irradiated and they lost constantly irradiation, that is why there is an important disparity. Unlike for the roof, the LOD3 irradiation is much lower than the two others due to the windows on the facades. In this case, a LOD2 model is not precise enough regardless of the surrounding materials.

Furthermore, a simulation with glazed surface to represent the windows on the surrounding buildings with a detailed glazing proprieties was run. No difference of annual irradiation was notice between it and the model with default materials. This is explained because the ratio of windows on all facades are relatively low (average of 20%) or the calculation nodes are too distant. In this case, modelling the glazing is not useful. However, in a district with a lot of glazed building, the results could lead to a higher yearly irradiation modelling the glazing.

2nd building

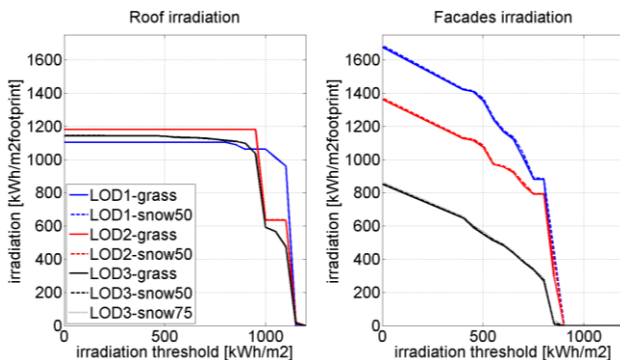


Figure 9 Difference between model with and without snow regarding the annual irradiation for the roof and for the facades

Plotting the annual irradiation to compare the model with snow and the model without snow, Figure 9 shows the results for the roof and facades irradiation separately. The first fact to

notice is: there is no difference of annual irradiation for the roof and a very small one for the façades (less than 2.5%). In this case, it is clear, modelling the snow proprieties is not advantageous to compare the annual irradiation contrary to the levels of details.

However, if we want to assess the PV potential to a lower scale of time (daily or hourly), it is possible to quantify the impact of snow for a winter day. To achieve this, the sunniest winter day of the weather file (17 march) is compared regarding the solar irradiation with and without snow for each surface of the roof and the facades.

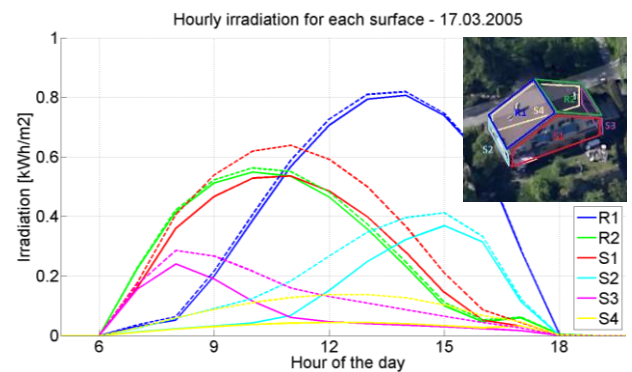


Figure 10 Hourly irradiation for the six surfaces of the building: two roof surfaces (R1, R2) and the four facades surfaces (S1 to S4) in order to compare the LOD3 model with grass 20% of reflectivity (continuous line) and this with snow 75% of reflectivity (dotted line)

The Figure 10 represents the irradiation on the surfaces of the building for the LOD3 model. We can identify the surface through the position of the top of the curve. When the top is before midday, it is representative of an east surface and when the top is after midday it is representative of a west surface as displayed in the graph's legend. (Surface of the roof R1 and R2 and surface of the façade S1 to S4). The analysis of the most irradiate surfaces (R1, R2, S1 and S2) is expand. For these surfaces, the comparison between LOD2 and LOD3 for a day with snow (s) and without snow (g) is done in Figure 11.

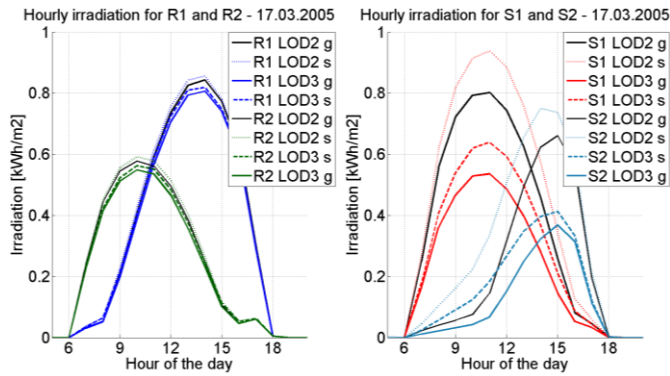


Figure 11 Hourly irradiation on the R1, R2, S1 and S2 surfaces for the 17 march

The curves are more scattered for the facades than the roof, it means that logically the reflectivity of the ground does not impact the roof. Furthermore, as there are not a lot of objects on the roof, the difference of irradiation between LOD2 and LOD3 is not significant. We can conclude that, for the roof in a suburban environment, modelling the materials is not profitable. The big factors for PV potential are the roof angle and direction and the rate of non-possible place to implement PV.

However, it is not the same situation for the facades. As they are more covered by windows, the irradiation of LOD3 is lower than LOD2 one. Moreover, the gain of irradiation in modelling snow is approximately 10% for the same level of detail. For example in our case, it corresponds to 0.1 kWh/m^2 during six hours, that is 600 [W] gained per square meter. If we assume an efficiency of PV of $0.15 [-]$, it is 90 [W] of useful energy, whether a light of an incandescent bulb of 60 [W] during 90 minutes per square meter of PV panel gained in modelling snow in our model. This type of model can be interesting when we want to assess precisely the gain of energy we can obtain in winter and match the demand with the production.

However, these results only apply for a sunny winter day with snow on the ground, for this reason, we don't perceive an annual change of irradiation in this environment. In Neuchâtel, there are less than twenty days like this during a year. However, if a house is located in a snowy environment, modelling the snow seems indispensable.

Limitations and future work

In this work we used an interspace between calculation nodes of one meter. However, there are external details as roof windows which are smaller than this interval. Thus these details could be neglected with this method. Furthermore, the surface of the terrain is supposed at the same high of the DTM points. In reality there are elements to consider, the vegetation is not modelled in this work for example.

The consideration of one material reflectance for all surrounding buildings is a simplification. This model does not take into account the difference of materials on the facades or the roofs. Moreover, the irradiation on a façade is largely dependent to the external elements on it. It might be worth to examine if we can link windows ratio on a façade and relative error for irradiation. Moreover, the results showed that the direct surrounding materials can have an impact on the solar irradiation and it depends of the environment. This report produces results representative of cities as Neuchâtel. Whether a study focuses on cities with glass façade skyscrapers, these results would be mistaken.

The big part of the irradiation is from the direct sunlight and the diffuse light. Only a small part is due to the reflection. It would be interesting to compare a model with reflections and another one without it.

This experiment was done for four case studies. Even this is a representative sample of style of buildings, this is a limited number. The future work is to repeat the experiment for the same type of buildings and check the relative errors. It would be interesting to add a building not studied as an industrial one.

Conclusion

This report presented an approach to find the relative errors of LOD1 and 2 considering LOD3 as the ground truth. The results showed that in most cases, the PV potential is overestimated in LOD1 and LOD2 model for buildings. The relative error depends of the thresholds and is bigger for higher threshold due to the small irradiation. The LOD2 relative error is commonly lower than the LOD1 one, especially for the roof. However, the relative error done with LOD1 and LOD2 are of the same magnitude.

This method could lead to an assessment of PV potential at the urban scale more precisely without needing a LOD3 model by using the correction factors. This will induce a significant gain of time avoiding a complex LOD3 modelling.

Regarding the assessment of exact material proprieties, the irradiation depends strongly of the environment. In a city as Neuchatel and on a large-scale (no high building and low ratio of glass on buildings), the default materials are appropriate. In this case, we demonstrated that modelling exact surrounding materials proprieties is not relevant.

Contrariwise, the specific cases shall be investigated. We saw that modelling materials as windows or specific ground can influence the irradiation on the facades. For example in the mountains, modelling the snow can increase the irradiation of 10% on a façade a sunny winter day. This gain of solar irradiation is not negligible when assessing the PV potential in the season the energy is needed. However, the irradiation on facades is always smaller than on roofs. Nowadays, it would be not economically viable to build PV panels on facades due to their prices and efficiency.

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